energies

Article

Mapping Seasonal Variability of Buildings Electricity Demand profiles in Mediterranean Small Islands

Simone Ferrari [1], Federica Zagarella [1,*], Paola Caputo [1] and Marco Beccali [2]

1 Department of Architecture, Built Environment and Construction Engineering (ABC), Politecnico di Milano, 20133 Milano, Italy
2 Dipartimento di Ingegneria, Università degli Studi di Palermo, 90128 Palermo, Italy
* Correspondence: federica.zagarella@polimi.it

Abstract: In communities with a high tourist influx and warm climate, such as Mediterranean small islands, the energy demands for space cooling and domestic hot water are expected to significantly increase during summer. Considering the current energy context, for succeeding energy transition and reducing the dependency on not endogenous fossil fuels, it is paramount to increase the deployment of renewable sources of energy, especially wind and solar which, however, are aleatory and unpredictable. Hence, to reduce the high costs for energy supply in these contexts, the analysis of the variation of energy consumption is fundamental. Moreover, mapping the spatial distribution of energy profiles can be useful to have an overview at a large scale of the considered building stock. Within this frame, a Geographic-Information-System-based procedure was implemented to estimate the residential buildings energy demand profiles, focusing on the seasonal variation. The adopted method can provide a valid supporting tool for decision makers that have to implement smart energy strategies in contexts with a high variation of the energy demand and evident electricity summer peaks. The method for mapping the energy demand profiles, implemented on the small island of Pantelleria, can be applied to other similar contexts, also supporting energy policies in the implementation of renewable energy communities.

Keywords: GIS; small islands; energy demand profiles; cooling electric peak; Mediterranean context; Pantelleria

Citation: Ferrari, S.; Zagarella, F.; Caputo, P.; Beccali, M. Mapping Seasonal Variability of Buildings Electricity Demand profiles in Mediterranean Small Islands. *Energies* **2023**, *16*, 1568. https://doi.org/10.3390/en16041568

Academic Editor: Alfredo Guardo Zabaleta

Received: 26 November 2022
Revised: 15 January 2023
Accepted: 1 February 2023
Published: 4 February 2023

1. Introduction

The European Commission launched the Green Deal with the aim of reaching climatic neutrality by 2050 in the European Union (EU) [1]. According to the outlined vision, a relevant role is given to the smart integration of renewable energy sources (RES) into the energy system. For this to happen, the energy market should be fully integrated, interconnected, and digitalized. Consequently, this transition entails the shift of citizens from a customers' role towards a more active involvement as prosumers. Within this framework, the entity of the "energy community", regulated in EU by Directives 2018/2001 [2] and 2019/944 [3] and in Italy by the Legislative decree 199/2021 [4], aims at facilitating the participation of individuals into the energy system, promoting self-consumption, production, management, and purchasing of energy from RES [5]. Moreover, the EU directive 2019/944 [3] recognizes the pioneering role of outermost regions in testing innovative and renewable-based energy technologies for the EU due to their isolation and dependence on fossil fuels.

In Italy, the National Plan of Recovery and Resilience [6], implementing the Next Generation EU [7], indicates the ecological and digital transition as the pillars towards achieving recovery after the pandemic period. Among the planned actions are investments aimed at realizing a mix of intersectoral solutions (energy and water efficiency, sustainable mobility, waste management, circular economy, exploitation of RES) in 19 small islands as challenging laboratories for testing the energy transition [8].

Small islands, defined as "detached land mass with a surface area less than 10,000 km^2 and a population of less than 500,000 inhabitants" [9], are fragile communities as they are seldom connected to the grid and have stand-alone power systems, mainly based on imported fossil fuels, which implies higher energy prices than on the mainland [10]. Many islands have a touristic vocation due to which they are seasonally affected by increasing waste production, and water and energy consumption [11]. The accomplishment of an energy balance between production and consumption is even more challenging in insular energy systems due to the low population and variable consumption [12]. For these reasons, small islands are at the forefront of developing strategies to reduce energy consumption and related greenhouse gas (GHG) emissions. Considering that they are usually characterized by an abundance of RES, mainly aleatory ones such as solar, wind, and waves, and by low building density, the development of microgrids offers the opportunity to provide flexible energy and reduce their dependence on the mainland [13]. However, the geographical limitations of insular areas, the technical limitations correlated to small-size grid reliability, and the environmental challenges due to protected areas hamper the opportunity to achieve RES-based insular energy systems [11]. Indeed, the successful example of Samsø Island, Denmark, demonstrated that the phasing out of all fossil fuels takes many years and involves several challenges [14].

To face these issues, the development of methods for the assessment of the insular energy systems through Geographic Information System (GIS), which is a consolidated tool for environmental [15] and energy [16] modelling, has gained attention in the literature. Several studies regard the identifying of the potential sites for the RES exploitation, evaluating their distances from constrained areas, and mapping the optimal ones through GIS. For instance, in [17], the optimal siting of offshore wind farms in the neighboring of Creta, Greece, was evaluated based on a multi-decision criteria method, taking into account the proximity to protected natural areas, the economic feasibility, the technical constraints, and the social acceptance of the project. In [18], the application of a multi-criteria decision method to select potential offshore wind farm sites in Jeju Island, South Korea, showed that the inclusion of distance from protected areas, human activities, and marine environments strongly reduced the number of feasible sites. Another multi-criteria analysis was conducted by [19] for the optimal location of photovoltaic (PV) panels in the case of the island of Tenerife, Spain. Instead, only technical parameters were considered for the optimal location of wind farms in the Fiji Islands by [20].

The studies mentioned so far did not include the energy demand among the criteria but included parameters only regarding the proximity to the settlements or transmission lines. For a proper integration of RES in the energy mix, the assessment of energy producibility must be accomplished together with the estimation of energy loads. As thoroughly discussed in [21], plenty of methods to estimate the energy demand, with different level of detail, is reported in the literature. In case of poor data quality, annually based consumption is commonly adopted. For instance, with reference to Bohol Island, Philippines, in [22], the annual load potentially served by each identified small-scale hydropower system was estimated based on the number of households and the data on national annual electricity consumption per capita. In [23], the measured annual electricity demand in the Canary Islands, Spain, was compared with the estimated energy potential from offshore wind fields. In [24], the yearly electricity consumption by building use category was determined for Reunion Island, France.

However, to properly integrate the renewables into the energy mix and manage the complex dispatchment between the related variable and aleatory energy supply fluxes with the variable demand-side strategies ones (peak shaving, storages, etc.), the adoption of time-aggregated energy demand cannot be adequate and can entail evaluating optimistic scenarios. To strengthen this issue, in [25], a survey was carried out on 17 existing tools for urban energy planning, which shows that the most detailed tools require the users to input load profiles with high time resolution. Specifically, in [26], a survey on bottom-up detailed tools for energy planning was carried out with regard to insular contexts and demonstrated that the most adopted time resolution in the literature is the hourly one. For instance, in [27], the RES penetration at minimum cost was investigated for the island of São Vicente, Cape Verde, with the H2RES tool [28], using hourly electricity consumption data. In [29], the ability to cover the electricity demand of off-grid island communities in Araceli, Balabac, and Cuyo Islands, Philippines, with PV panels was investigated by means of hourly energy demand data provided by the local distribution utility. In [30], the optimal system configuration including RES to meet the electricity requirement of Gökçeada Island, Turkey, was analyzed with HOMER tool [31] by determining typical daily profiles for winter and summer periods based on data from the local electric utility.

As pointed out in [26], most of the studies on islands focused on the power sector, although the assessment of different energy sectors would allow the investigation of synergies and flexibility options. In [32], the opportunity of achieving energy independence in Agathonisi Island, Greece, based entirely on RES was investigated with the HOMER tool. The proposed system configuration includes a mix of solutions (i.e., wind turbines, PV panels, batteries, and an internal combustion-electric generator consuming biogas) to meet the electrical, domestic hot water (DHW), and thermal demands. These ones were estimated based on historical electricity data, the typical daily DHW profile in dwellings, and considering only energy exchange for transmission and ventilation, respectively. In [33], the techno-economic feasibility of heat recovery from the existing diesel engines-based power plants and the possible distribution of heat to supply energy loads of both residential and non-residential users were assessed for 6 small islands in Italy (Isola del Giglio in the central area of Italy, plus Lampedusa, Linosa, Ustica, Pantelleria, and Favignana in the south), revealing that, due to the low linear heat density, the investments would not be attractive, making hardly achievable the 100% RES scenario, unless public support mechanisms are adopted. The monthly demands for residential space heating and cooling energy were calculated by means of dynamic energy simulations, whereas the non-residential ones were based on statistical correlations.

Focusing on the small Sicilian islands, which have common features in terms of climate, tourist vocation, and building stock, the literature includes studies with different scopes. In [34], a techno-economic feasibility analysis of a hybrid multi-purpose plant, based on an Organic Rankine Cycle supplied by medium-enthalpy geothermal energy and solar energy, was investigated for the island of Pantelleria. The study returned that the system is economically profitable only when most of the produced energy for meeting the annual space heating and cooling demand is used. In [35], a methodology to size battery energy storage systems was defined and applied to the case study of Pantelleria. The authors concluded that the techno-economic optimal scenario would lead to a 70% RES integration although some system secure operation issues would arise. In [36], RES scenarios to meet the overall electricity demand of Salina Island were investigated in accordance with management and preservation measures. The implementation of PV panels on all existing dwellings would guarantee the production of one-third of the total annual energy demand, whereas a non-invasive installation of PV would meet the energy requirement of all tourists. In [37], the possibility to integrate solar and sea wave sources into the energy mix of Ustica to meet the energy demand of public buildings and facilities was investigated. As a result, the adoption of these two sources, which are more productive in summer and winter, respectively, was found fundamental to cover the electrical energy demand and stabilize the electricity production during the year. In [38], the hourly energy demand of dwellings and hotels in Lampedusa was estimated, based on data from an accomplished survey. The study results show that the island's electricity consumption is higher than the national average; the winter consumption is higher than summer ones probably due to more intensive use of lighting systems, electricity-based heating systems and electric storage domestic water heaters during the coldest months; and that the DHW demand peaks occur in the early morning and the afternoon. Moreover, some peaks due to air-conditioning system were observed during critical months. In [39], a feasibility study of a load management system for microgrids in the case of Lampedusa was developed. The hourly energy consumption was determined based on data from the local electrical service, surveys of the distribution system and the buildings, and interviews with the inhabitants. The study shows that a typical apartment consumes 4500 kWh of electricity per year, i.e., 50% more than an average Italian family.

The accomplished literature survey shows that the estimation of energy loads with a high time resolution, at least hourly, is a fundamental prerequisite to optimal plan smart energy communities. Moreover, it shows that the accurate mapping of diverse energy demand fluxes in the islands still needs investigation. Therefore, this study is intended to answer the research question of how to estimate and map, in case of low-quality data, the buildings hourly based energy demand profiles, both thermal and electrical, of the residential sector, as the main responsible of insular electricity consumption [38], stressing the issue related to seasonal variability. Hence, the novelty of the study is in the estimation and visualization of energy data with both high temporal and spatial resolution. To that end, in the frame of a research agreement signed by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and Politecnico di Milano, a GIS-based method was developed as a tool supporting planners in energy transition policies and is presented hereinafter.

2. Materials and Methods

Starting from previous research targeted on typical urban contexts [40], a method to estimate the residential buildings' energy demand hourly profiles in small islands was defined, with an application to the island of Pantelleria, Sicily (southern Italy), as representative of remote urban areas featured by high electric peaks in summer season (Section 2.1).

As a first step, the method foresees defining and simulating, through a dynamic energy simulation software, the hourly electric and thermal energy density load profiles (energy load per building volume unit expressed as [W/m^3]) for a set of Building Energy Models (BEMs), which are defined based on a Building Energy Concept (BEC), i.e., a simplified building geometry alternatively featured by technological solutions typical of the different periods of construction (Section 2.2).

Then, on the basis of the procedure described in [41], the method encompasses the mapping and characterization, based on available spatial data, of the residential building stock volume (Section 2.3) by the period of construction, which allows accounting building envelope features, and dwellings occupancy which is affected by a relevant seasonal variability. Additionally, the spatial assessment of installed thermal systems is carried out so that typical efficiencies of heating and cooling systems can be associated.

As an outcome, by associating the characterized built volume with the values of hourly energy density for space heating need, space cooling need, and electricity demand for appliances and artificial lighting, the considered building stock energy profiles are obtained (Section 2.4). Then, by associating the thermal system types and related efficiencies, the building stock energy consumption profiles are determined. Moreover, the monthly influx of tourists is used to correct the energy demand profiles. Additionally, the DHW demand is determined by correlating statistical data on annual energy demand in Italy with hourly profiles from surveyed building samples in Pantelleria. The method is validated with the annual data from the available energy balance.

2.1. Case Study Selection

The method summarized above was applied to the island of Pantelleria, one of the thirty minor islands in Italy, which was selected as a typical example of islands with high electric peaks in the summer season due to tourist influx.

Pantelleria (LAT 36°47′ N, LONG 11°59′ E) is a small island belonging to Sicily from which it is 110 km south; therefore, it is far away from the main energy distribution network, making the self-sufficiency issue a pivotal element of development and security.

The island has a surface of 84.5 km^2, mostly covered by hills, it includes the main town with the harbor and service buildings (educational, health, commercial, and tourism) on the northwest coast, together with many remote minor villages sparse on the territory (Figure 1). It has a warm temperate climate and 717 Heating Degree Days (HDDs), so it belongs to the Italian climate zone B according to the national classification [42]. It is featured by high average annual solar radiation (2100 kWh/m^2) and wind speed (7 m/s at 25 m over the sea level), which make the island interesting for renewable sources exploitation. In 2011 the entire island accounted for 7846 residents and a population density of around 90 people per square kilometer [43] but, notably, in summer it can reach up to 11,000 people due to tourists [44] as shown in Figure 2. For decades, the island's economy has been mostly based on tourism-related activities, due to which a strong increase in the population and related energy consumption occurs from May to September. Regarding its building stock, in 2011 it accounted for 6280 buildings, 5281 of which were residential [43] (these data can also be substantially assumed currently because new buildings on Pantelleria are very rarely built due to restrictions).

Figure 1. Localization of Pantelleria Island in the Italian territory (**a**); satellite maps of Pantelleria Island with the indication of villages (**b**); GIS map of Pantelleria Island with the indication of villages and residential building stock (**c**).

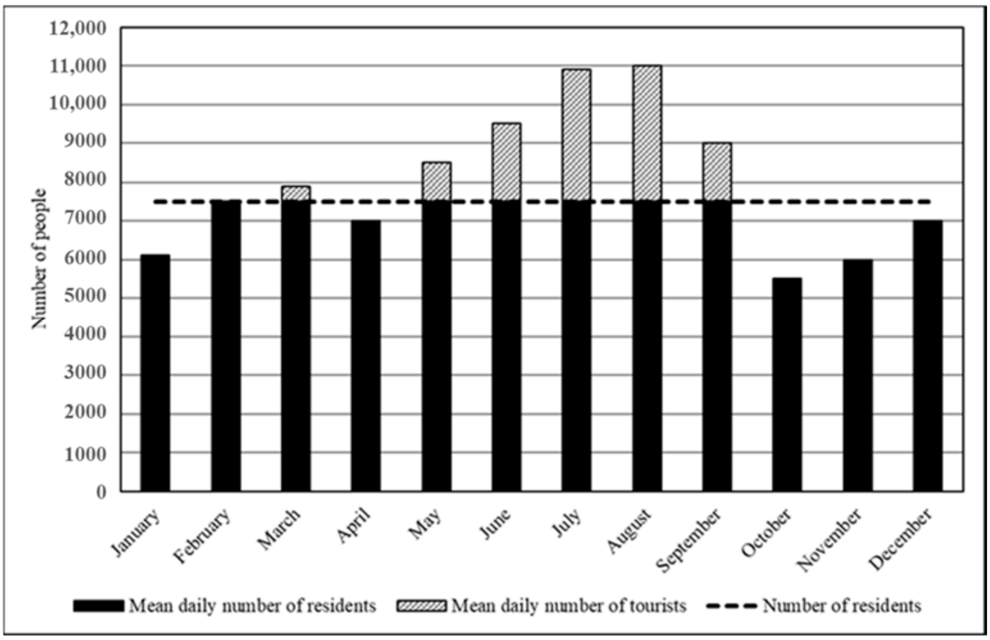

Figure 2. Mean daily number of people per each month, adapted from [44].

2.2. Building Energy Models Definition

The Building Energy Concept is intended as a simplified building geometry composed of typical thermal zones affecting different heat exchange behaviors, based on the combinations of horizontal and vertical boundary conditions, as described with more details in [40].

Based on the BEC, alternatively featured by technological solutions typical of the different periods of construction, the BEMs are defined as representative of the considered building stock. In the case of remote areas such as small islands, the customization of BEMs envelope features should be pursued even more than in the urban areas due to local vernacular architecture peculiarities. To that end, an architectural survey is necessary to deepen the constructive and thermophysical features of existing buildings. Indeed, Pantelleria Island is well known due to the local ancient rural buildings called “dammusi”, used as houses and warehouses and having dry-stone walls and stone dome, which lead to an envelope with high thermal inertia. Therefore, for this case study, three BEMS were defined considering three main periods of construction, i.e., “old”, referring to the “dammuso” buildings and modelled according to the technical literature [45], “from 1946 to 1990”, and “from 1990”, referring to buildings having envelopes with cavity walls, uninsulated and insulated, respectively, modelled according to [46].

Then, considering the results from the comparative study of standard internal heat loads profiles [47], the recommendations of the recent standard EN ISO 52000-1 [48] and subordinated ones, i.e., the ISO 17772:2017 part 1 [49] and 2 [50] and the EN 15193:2017 [51], were considered to model the occupants’ activities and electric device usage, which influence both the internal heat loads and the electricity consumption. The same standard ISO 17772:2017 was considered to set the air change per hour (ACH) due to ventilation and infiltration. The space heating season length and the number of hours per day were defined based on the HDDs for Pantelleria [42]. Conversely, since any national rule does not concern the cooling one, it was assumed according to occupants’ presence for the rest of the year. Furthermore, according to the standard ISO 17772-1:2017, comfort requirements were expressed in terms of operative temperature. The operative temperature parameter, commonly neglected in simplified building energy assessment which considers only the air temperature, can strongly influence the real building energy need. As a matter of fact, in the case of unfavorable radiant temperatures, the air temperature set-point is usually corrected by the users to adjust the indoor condition to compensate for the radiative component, and the consequent overuse of the active climatization systems causes an unpredicted increase in building energy consumption. Considering this, operative temperatures of 20 °C for heating were set as the indoor comfort temperatures. In addition, for a more proper evaluation of the energy performances during the cooling season, variable operative temperature values, calculated from the climatic data of Pantelleria, were adopted according to the adaptive approach assumption [52]. Moreover, considering that in the studied context, residential buildings are widely naturally ventilated, a free cooling strategy in summer was modeled [52]. BEMs dynamic energy simulations were performed with TRNSYS tool [53] adopting the proper test reference year (TRY) from TRNSYS library (IT-Pantelleria-Is-164700.tm2), to determine, under conditions unconstrained by the climatic situation of a particular year, the space heating and cooling need, and electricity demand hourly based profiles. Since a random orientation of buildings in large contexts can be assumed, the average energy performance from the simulations results, obtained by rotating the model based on the 4 main orientations (north, south, east, and west), has been applied to the considered building stock with good approximation. Moreover, the DHW energy demand was determined by correlating the average annual energy demand per dwelling according to [54] and the typical daily hourly profile determined in [55] thanks to data from a sample of surveyed dwellings in the nearest island, Lampedusa.

2.3. Building Stock Mapping

The island residential building stock mapping was developed in QGIS software [56] and includes the execution of some routines developed in Python.

As also highlighted in [24,36], small islands' energy demand mapping is generally hampered by a seriously low quality of data. Nevertheless, two data sources have been retrieved to characterize the building stock of Pantelleria Island. The building cadaster vector layer was requested by the Municipality office [57] to determine the buildings' footprints dimensions and location. Since the considered building stock is relatively small, to isolate the residential buildings object of this study, detailed removing all single not-residential buildings from the building cadaster vector layer by visual analysis of the town detailed masterplan [58] and the satellite images [59] required a sustainable effort.

The data from the 15th General Census of Population and Houses (GCPH), i.e., the last census conducted by the National Institute of Statistics (Istat) at the same time on the entire country [43], were elaborated on to determine the consistency of residential buildings and the dwelling occupancy. Remarkably, Istat provides the data per each Census Unit (i.e., a group of a few buildings corresponding to the smallest statistical unit used by Istat to collect data); therefore, as downscaling the GCPH data at the building level is not possible, the Census Unit was adopted as the reference scale of the defined method. The GCPH data used are the number and net surface of residential building units with residents, the number of residential building units with non-residents, the number of empty residential building units, and the number of resident families. The data used to characterize the residential built volume by technological solutions is the number of building units per each period of construction (<1919, 1945–60, 1961–70, 1971–80, 1981–90, 1991–2000, 2001–2005, >2005). Since the data from the GCPH are aggregated at the Census Unit level, a prevailing period per Census Unit was determined as the one for which the highest number of residential building units was reported and associated with all the buildings included in each Census Unit [41].

The GCPH was also used, i.e., the number of residential buildings per each number of floors (1, 2, 3, at least 4 floors) data, to determine the built volume in absence of building height data in the building cadaster vector layer. In detail, the sum of buildings' footprint surfaces per each Census Unit was split into four groups in proportion to the number of buildings having 1, 2, 3, or at least 4 floors, according to the GCPH. Then, a typical height was assumed and associated with each share of floor areas (data from the building cadaster vector layer), considering 3 m per floor.

As discussed in the literature review, Mediterranean small islands are strongly affected by seasonal variations of energy consumption with higher summer peaks due to tourists' influx. To consider this aspect, the determined residential building stock volume was split into two shares referred to as permanent houses and holiday homes. To this end, based on data from the GCPH, for each Census Unit the sum of residential units with residents was considered as a permanent house, whereas those with non-residents as holiday homes. The assessment returned 3312 permanent houses and 1627 holiday homes.

Furthermore, the GCPH provides the residential use surface served by each different thermal system type. In detail, the data utilized to assess the installed thermal systems are the building unit surface, the distribution systems type (centralized or individual), the space heating systems fuel, the type of DHW systems (combined or DHW-only), the thermal system fuel in the DHW-only case, and the presence of a space cooling production unit. Subsequently, the percentages of different heating and DHW systems were calculated based on the residential building units' heated surfaces. Conversely, for space cooling, the percentage was referred to the presence of cooling systems in the building units, as the only available data, which were all assumed as electricity-based multi-splits [60]. In the case of Census Units with missing data, the average systems distribution among the surrounding Census Units was adopted. Then, based on [61], typical mean thermal system efficiencies were associated with each Census Unit for each thermal system type.

2.4. Buildings Energy Profiles Assessment

The simulated energy profiles per each BEM were associated with each Census Unit built volume based on the related period of construction and dwelling occupancy. In detail, the nine periods of construction from the GCPH were grouped into three ones (<1945, 1945–1990, and >1990) consistently with the BEMs. Remarkably, the energy profiles were associated with the permanent houses for the whole year, and with the holiday homes, only during the tourist season. Hence, by associating the space heating, DHW, and space cooling systems efficiencies with the built volume, the energy consumption profiles of the residential building stock were obtained.

To strengthen the issue related to seasonal variability of energy consumption, based on the mean daily number of people per month [44] and the known number of residents [43], a percentage of occupied residential built volume, divided by permanent houses and holidays homes, was calculated per each month and used to recalculate the hourly based electricity profiles with a different amplitude on monthly base (Figure 3). As a result, it was observed that the highest monthly electricity consumption, which occurs in July (1689 MWh), is almost 3 times than the lowest one (608 MWh), which occurs in October. Despite this, the permanent houses, on a yearly basis, comprise 80% of the island power load, whereas the holiday homes total 20%. In detail, the permanent houses require 43% of the overall electricity consumption for the equipment and artificial lighting, 25% for the DHW, 10% for space heating, and 2% for space cooling; the holiday homes require 10% for the equipment and lighting, 9% for the DHW, and 1% for space cooling. Moreover, it must be noted that the electricity demand for equipment and artificial lighting and for DHW represent the highest contributions to the residential building stock electricity consumption, as they account for 53% and 34%, respectively. The demand for thermal space is less impacted, as the space heating contribution accounts for 10% and the space cooling only for 3%.

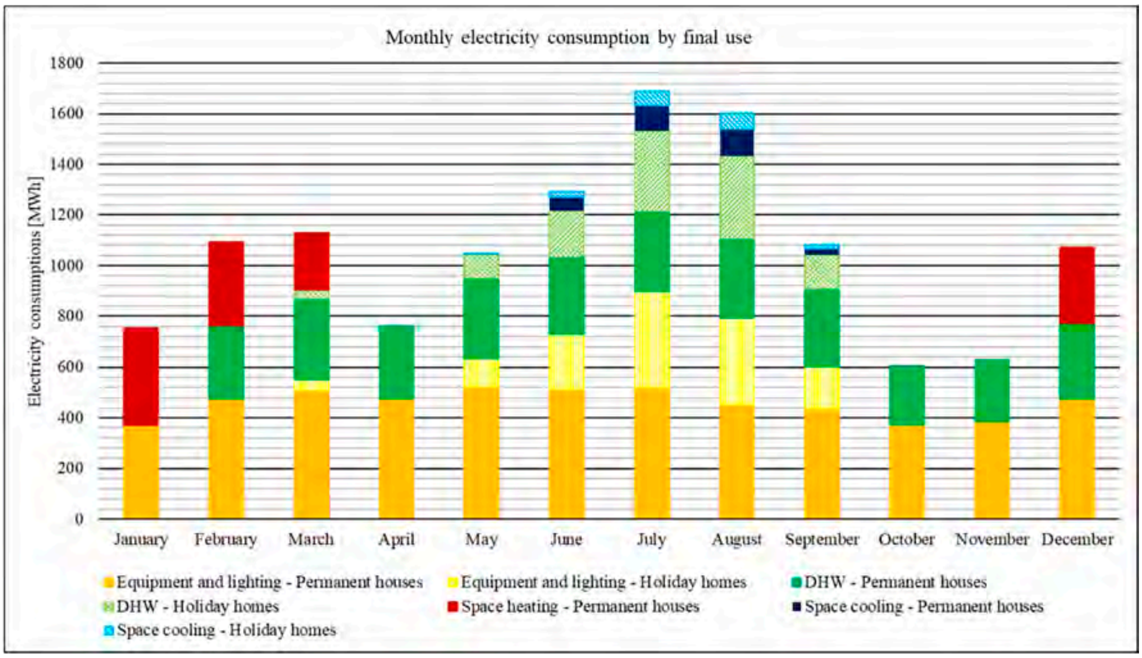

Figure 3. Monthly electricity consumption by final use in Pantelleria.

To verify the robustness of the method, a twofold validation was carried out regarding the residential built volume and the residential sector electricity consumption. Concerning the former, the residential built volume obtained by means of the procedure (3.34 Mm^3) was compared with the one elaborated based on data from Istat (3.23 Mm^3), obtaining a gap of +3%. Concerning the latter, in absence of more detailed and consistent data, the residential sector’s annual electricity consumption in 2013 from the Sustainable Energy Action Plan [60], elaborated as 11.81 GWh, was compared with the one determined by the procedure, prior normalization with the heating and cooling degree days in 2013, equal to 12.5 GWh, thus revealing a gap of only +5.88%.

3. Results and Discussion

In the context of small islands, the identification of areas with different load densities is fundamental for optimal planning of the large-scale implementation of energy efficiency measures on either buildings envelope or decentralized RES-based systems, including the integration of storages for balancing the possible production-demand mismatch, especially in off-grid contexts. The implementation of this method allows generating maps that can support this purpose. In the following, examples of maps are reported for the investigated case study both regarding the building stock features, as a first screening action, and the energy profiles, to deepen the energy seasonal variation issue.

In Figure 4, the Census Units of Pantelleria were mapped by the main period of construction. As an example of findings, it can be observed that the oldest building stock, featured by greater thermal inertia, is prevailing in the proximity of the main town, whereas the rest of the island is dominated by 60s/80s buildings with uninsulated envelope, except for some rural/touristic areas in the northern and southern parts with the higher number of new buildings.

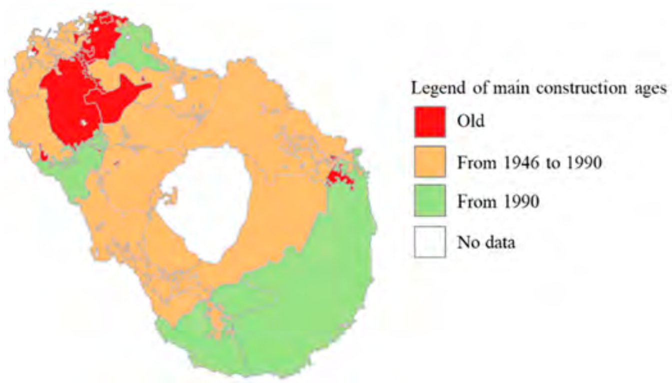

Figure 4. Maps of Census Units per period of construction in Pantelleria.

In Figure 5, the Census Units of Pantelleria are mapped by use category percentages. It can be noted that residential use is prevailing in the Census Units with villages, whereas buildings dedicated to other uses (commercial activities, hotels, etc.) are prevailing in the rural/touristic areas.

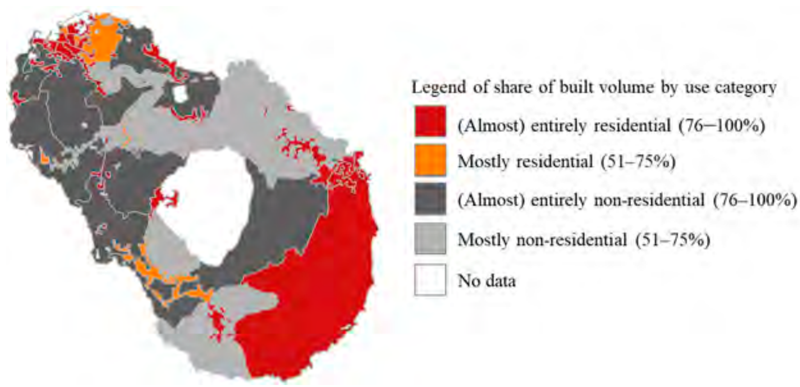

Figure 5. Maps of Census Units per use category in Pantelleria.

In Figure 6, the Census Units of Pantelleria are mapped by dwelling occupancy in terms of percentage of residential volume for permanent houses and holiday homes. It can be noted that the former ones are prevailing in the greater villages, whereas the latter prevail in the rural/touristic areas.

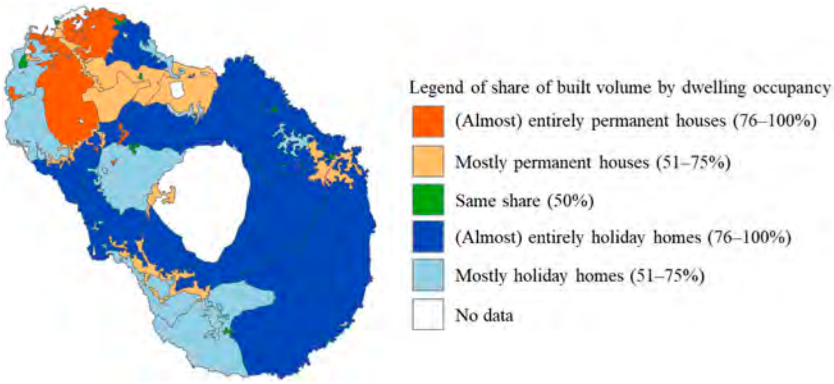

Figure 6. Maps of Census Units per dwelling occupancy in Pantelleria.

In the following, maps of energy intensity in three different hours, selected as an example, are reported per each Census Unit and differently colored based on the energy intensity ranges.

In Figure 7, the maps show the space heating needs in a typical (average) winter workday. From a spatial perspective, the space heating need prevails in the main town and other more urbanized villages in the south area (Khamma, Tracino, Scauri); from a temporal perspective, it is higher in the morning due to lower temperatures.

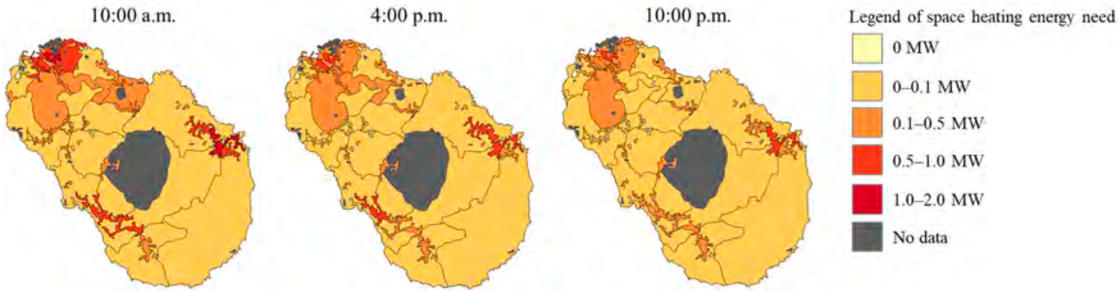

Figure 7. Maps of Census Units per space heating energy need in Pantelleria.

In Figure 8, the maps show the space cooling needs in a typical (average) summer workday. Spatially, the space cooling need dominates in the south area of the island, which is characterized by a higher presence of tourists; temporally, it increases during the day until the evening peak, consistently with higher temperatures.

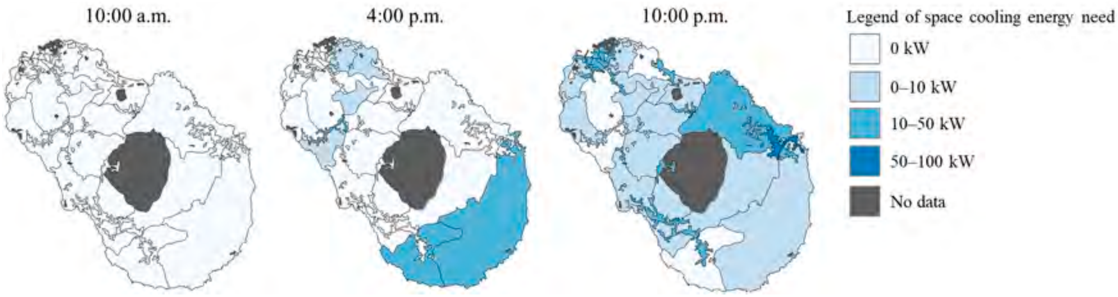

Figure 8. Maps of Census Units per space cooling energy need in Pantelleria.

The electricity demand for appliances and artificial lighting is reported for a typical winter day in Figure 9 and for a summer day in Figure 10. The maps show that the demand is clearly widespread throughout the entire island, whereas it prevails in greater villages and, in summer, in the southern areas dominated by the tourists' presence. Moreover, in all seasons an evening peak is observed due to the return of people at home from work or beaches.

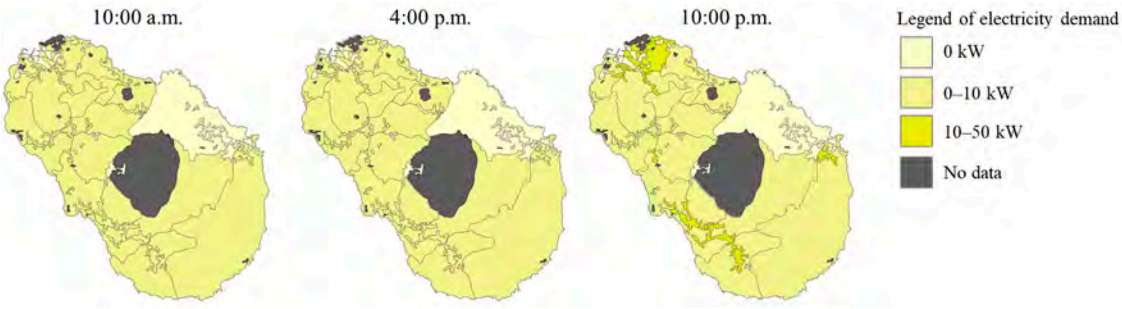

Figure 9. Maps of Census Units per electricity demand in winter in Pantelleria.

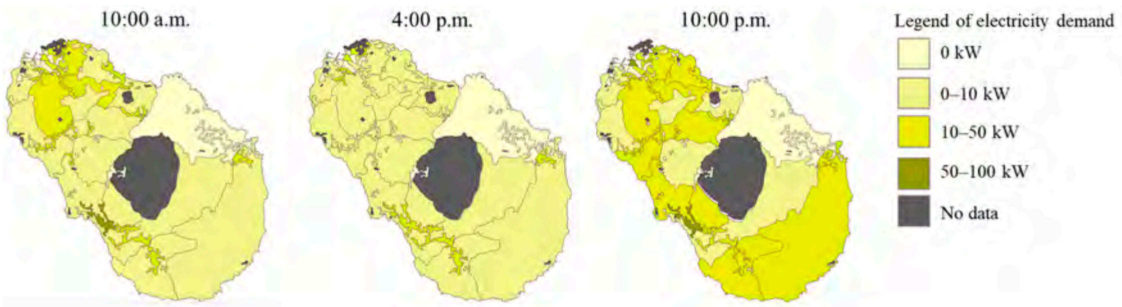

Figure 10. Maps of Census Units per electricity demand in summer in Pantelleria.

The energy need for DHW is reported for a typical winter day in Figure 11 and for a typical summer day in Figure 12. Although with different intensities, the spatial and temporal trends are similar to those of the electricity demand for appliances and artificial lighting.

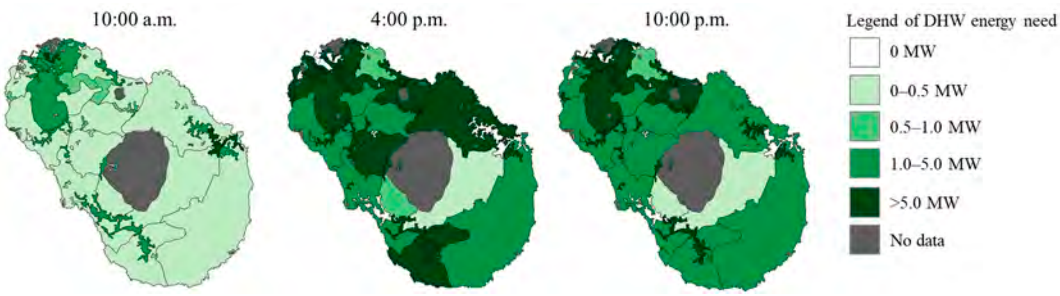

Figure 11. Maps of Census Units per DHW energy need in winter in Pantelleria.

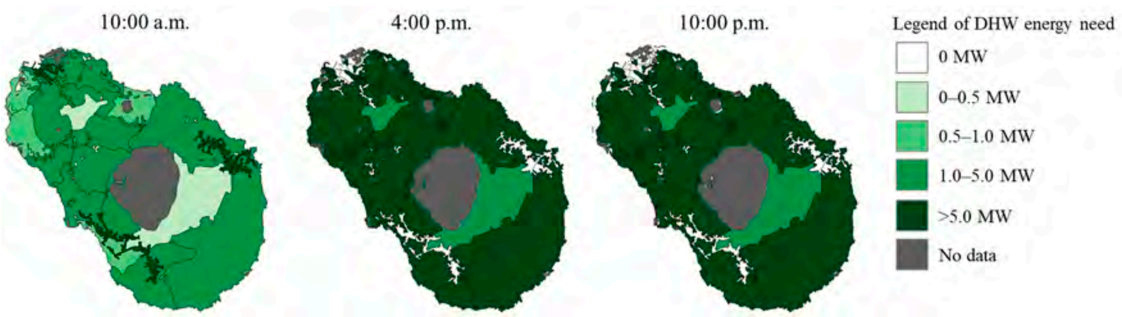

Figure 12. Maps of Census Units per DHW energy need in summer in Pantelleria.

To investigate the seasonal variation of the residential building stock energy consumption, the winter and summer weeks returning the highest electricity consumption during the year were identified and assessed.

In Figure 13, the profile associated with the winter week with the highest electricity consumption, entirely due to permanent houses, is reported. It can be observed that the daily greatest consumption peak occurs in the evening, whereas the two remaining lower peaks occur in the early morning and lunchtime. All of them are probably linked to the return of resident people from work/school activities and, indeed, are mainly affected by equipment, lighting, and DHW use. Moreover, the daily pattern is similarly repeated during the entire week, likely due to homogeneous climatic conditions and occupancy profiles. The weekly power load (327 MWh) is affected by 23% by space heating, 36% by equipment and lighting, and by 41% by DHW.

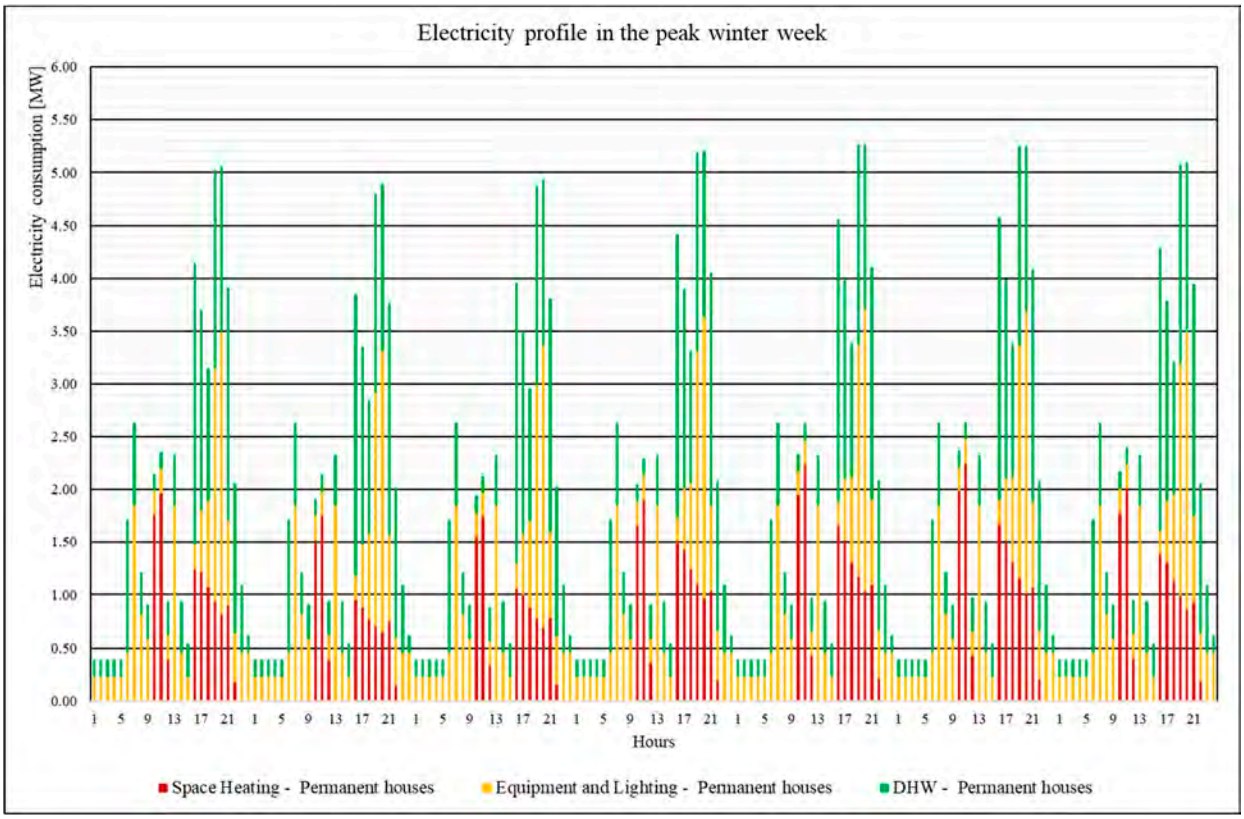

Figure 13. Pantelleria hourly based electricity consumption profile for space heating, equipment and artificial lighting, and DHW in a winter week.

In Figure 14, the profile associated with the summer week with the highest electricity consumption, due to both permanent houses and holiday homes, is reported. The daily greatest consumption peak occurs in the evening, possibly related to the return from work and beaches. Interestingly, due to a strong variation of climate conditions in summer, daily profiles with quite a different magnitude during the week can be observed. The weekly power load (607 MWh) is affected by 28% by space cooling, 34% by equipment and lighting, and by 38% by DHW. The relevant contribution of the holiday homes, which are responsible by even 41% of the whole weekly load, implies that the summer peak (19.4 MW) power is around three times higher than in the winter (5.3 MW).

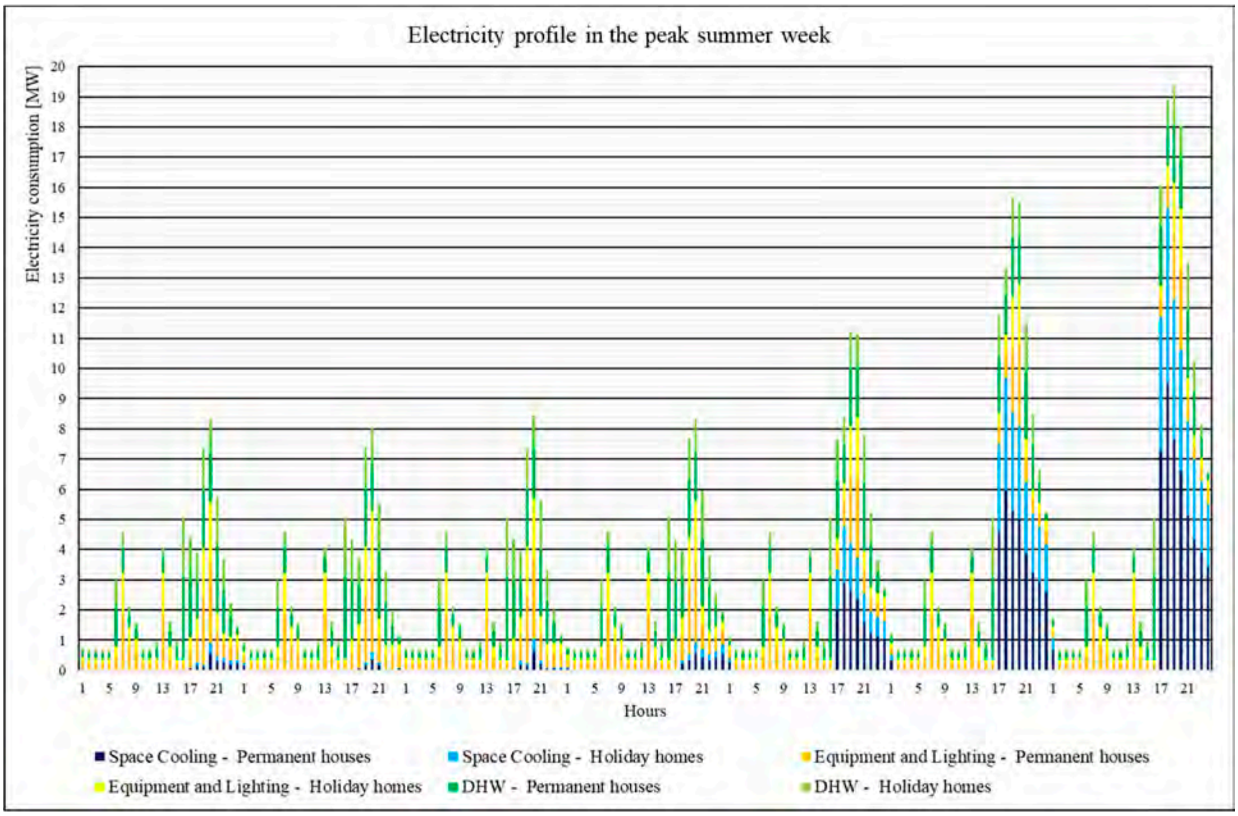

Figure 14. Pantelleria hourly based electricity consumption profile for space cooling, equipment and artificial lighting, and DHW in a summer week.

4. Conclusions

Small islands are at the forefront of accomplishing energy transition through measures at a community scale. Moreover, they are fragile systems due to high seasonal energy fluctuation, high energy costs, and dependence on fossil fuels. A previously developed method for mapping the urban building stock energy profiles, which can be deepened in properly mentioned references, was improved to fit with insular contexts. In detail, a Geographic-Information-System-based procedure was implemented to estimate the residential buildings' energy demand profiles in small islands, with a focus on the seasonal variation in electrical demand. The procedure was tested on Pantelleria Island, in Southern Italy.

The main outcomes of the method are the maps generated for the spatial analysis of residential buildings' energy-related features and hourly energy demand, as a tool supporting the identification of sites where investing in energy measures and/or energy communities' promotion. As an example, the maps of Census Units' prevailing period of construction, use category percentage, and dwelling occupancy as well as space heating, space cooling, equipment and artificial lighting, and domestic hot water energy demand in selected hours of the year are here reported. Moreover, an insight into weekly electricity profiles in winter and summer allows for investigation into the different contributions of final uses and of the tourists' consumption.

The impact of this method is valuable because the determined hourly profiles could be used as input data in the detailed energy planning software (e.g., Homer, EnergyPLAN, etc.) for properly investigating new energy production mix scenarios (e.g., integration of renewable energy sources and storages, implementation of microgrids) and develop energy plans.

The present study shows that the previously defined method can be also adopted in complex contexts such as small islands, featuring data from low-quality buildings. Due to the adopted data sources, the method implemented in the context of the small island is currently limited to the residential building stock; further development of this research could regard the assessment of other use categories responsible for relevant seasonal energy consumption, such as hotels and commercial buildings.

Author Contributions: Conceptualization, S.F.; Methodology, S.F.; Software, F.Z.; Validation, P.C. and M.B.; Formal analysis, S.F. and F.Z.; Investigation, S.F. and F.Z.; Writing – original draft, P.C. and F.Z.; Writing – review & editing, S.F., P.C. and M.B.; Visualization, S.F and F.Z.; Supervision, S.F.; Project administration, S.F.; Funding acquisition, S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded in the Program Agreement between the Italian National Agency for New Technologies, Energy and Sustainable Economic Development ENEA and the Ministry of Economic Development (now Ministry of the Environment and Energy Safety) for the Electric System Research, in the framework of its Implementation Plan for 2019–2021. The activity is included in the Project 1.5 "Technologies, techniques and materials for energy efficiency and energy savings in the electrical end uses of new and existing buildings", Work Package 4 "Integrated Energy Networks".

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions*; The European Green Deal, vol. COM(2019) 640 final; European Commission: Brussel, Belgium, 2019.
2. European Parliament, Directive (EU). *2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources*; European Parliament, Directive (EU): Luxembourg, 2018.
3. European Parliament, Directive (EU). *2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive*; 2012/27/EU; European Parliament, Directive (EU): Luxembourg, 2019.
4. Italian Parliament. Decreto Legislativo 8 Novembre 2021, n. 199. Attuazione Della Direttiva (UE) 2018/2001 del Parlamento Europeo e del Consiglio, dell'11 Dicembre 2018, Sulla Promozione Dell'uso Dell'energia da Fonti Rinnovabili. Gazzetta Ufficiale n.285 del 30-11-2021—Suppl. Ordinario n. 42, Rome, Italy. 2021. Available online: https://www.gazzettaufficiale.it (accessed on 14 January 2023).
5. Biresselioglu, M.E.; Limoncuoglu, S.A.; Demir, M.H.; Reichl, J.; Burgstaller, K.; Sciullo, A.; Ferrero, E. Legal Provisions and Market Conditions for Energy Communities in Austria, Germany, Greece, Italy, Spain, and Turkey: A Comparative Assessment. *Sustainability* **2021**, *13*, 11212. [CrossRef]
6. Italian Government. *Piano Nazionale di Ripresa e Resilienza (PNRR)*; Italia Domani; Italian Government: Rome, Italy, 2021. Available online: https://www.governo.it/ (accessed on 14 January 2023).
7. European Commission. *Recovery Plan for Europe. Next Generation EU (NGEU)*; European Commission: Brussel, Belgium, 2021.
8. Ministero Della Transizione Ecologica, Decreto Direttoriale n.390 del 25 Novembre 2021. Programma Isole Verdi, nell'ambito del Piano nazionale di ripresa e resilienza (PNRR); GU Serie Generale n. 296 del 14-12-2021. 2021.
9. Ozuem, W.; Thomas, T. Inside the Small Island Economies: Loyalty Strategies in the Telecommunications Sector, in Telecommunications Sector. In *Handbook of Research on Global Business Opportunities*; Christiansen, B., Ed.; IGI Global Publisher: Hershey, PA, USA, 2015; pp. 316–349.
10. Beccali, M.; Finocchiaro, P.; Ippolito, M.G.; Leone, G.; Panno, D.; Zizzo, G. Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: A case study. *Energy* **2018**, *157*, 106–114. [CrossRef]
11. Erdinc, O.; Paterakis, N.G.; Catalao, J.P. Overview of insular power systems under increasing penetration of renewable energy sources: Opportunities and challenges. *Renew. Sustain. Energy Rev.* **2015**, *52*, 333–346. [CrossRef]
12. Notton, G. Importance of islands in renewable energy production and storage: The situation of the French islands. *Renew. Sustain. Energy Rev.* **2015**, *47*, 260–269. [CrossRef]
13. Kuang, Y.; Zhang, Y.; Zhou, B.; Li, C.; Cao, Y.; Li, L.; Zeng, L. A review of renewable energy utilization in islands. *Renew. Sustain. Energy Rev.* **2016**, *59*, 504–516. [CrossRef]
14. Sperling, K. How does a pioneer community energy project succeed in practice? *The case of the Samsø Renewable Energy Island. Renew. Sustain. Energy Rev.* **2017**, *71*, 884–897. [CrossRef]
15. Li, J.; Tian, Y.; Zhang, Y.; Xie, K. Spatializing environmental footprint by integrating geographic information system into life cycle assessment: A review and practice recommendations. *J. Clean. Prod.* **2022**, *323*, 129113. [CrossRef]
16. Wong, C.; Hin, H.; Cai, M.; Ren, C.; Huang, Y.; Liao, C.; Yin, S. Modelling building energy use at urban scale: A review on their account for the urban environment. *Build. Environ.* **2021**, *205*, 108235. [CrossRef]

17. Gkeka-Serpetsidaki, P.; Tsoutsos, T. A methodological framework for optimal siting of offshore wind farms: A case study on the island of Crete. *Energy* **2022**, *239 Pt D*, 122296. [CrossRef]
18. Kim, T.; Park, J.-I.; Maeng, J. Offshore wind farm site selection study around Jeju Island, South Korea. *Renew. Energy* **2016**, *94*, 619–628. [CrossRef]
19. Gutiérrez, J.; Velázquez, J.; Aguiló, M.L.; Herráez, F.; Herráez, C.; Canelo, L.E.; Hernando, A.; Gómez, I.; Rincón, V. Multi-Criteria Methodology for the Location of Photovoltaic Solar Energy Production Facilities in Tenerife (Spain). *Infrastructures* **2022**, *7*, 28. [CrossRef]
20. Dayal, K.K.; Cater, J.E.; Kingan, M.J.; Bellon, G.D.; Sharma, R.N. Wind resource assessment and energy potential of selected locations in Fiji. *Renew. Energy* **2021**, *172*, 219–237. [CrossRef]
21. Ferrari, S.; Zagarella, F.; Caputo, P.; D'Amico, A. Results of a literature review on methods for estimating buildings energy demand at district leve. *Energy* **2019**, *175*, 1130–1137. [CrossRef]
22. Torrefranca, I.; Otadoy, R.E.; Tongco, A. Incorporating Landscape Dynamics in Small-Scale Hydropower Site Location Using a GIS and Spatial Analysis Tool: The Caseof Bohol, Central Philippines. *Energies* **2022**, *15*, 1130. [CrossRef]
23. Schallenberg-Rodríguez, J.; Montesdeoca, N.G. Spatial planning to estimate the offshore wind energy potential in coastal regions and islands. Practical case: The Canary Islands. *Energy* **2018**, *143*, 91–103. [CrossRef]
24. Bénard-Sora, F.; Praene, J.-P.; Calixte, Y. Assess the local electricity consumption: The case of Reunion island through a GIS based method. *AIMS Energy* **2018**, *6*, 436–452. [CrossRef]
25. Ferrari, S.; Zagarella, F.; Caputo, P.; Bonomolo, M. Assessment of tools for urban energy planning. *Energy* **2019**, *176*, 544–551. [CrossRef]
26. Prina, M.G.; Groppi, D.; Nastasi, B.; Garcia, D.A. Bottom-up energy system models applied to sustainable islands. *Renew. Sustain. Energy Rev.* **2021**, *152*, 111625. [CrossRef]
27. Segurado, R.; Costa, M.; Duić, N.; Carvalho, M. Integrated analysis of energy and water supply in islands. Case study of S. Vicente, Cape Verde. *Energy* **2015**, *92*, 639–648. [CrossRef]
28. Duić, N.; Lerer, M.; Carvalho, M.G. Increasing the supply of renewable energy sources in island energy systems. *Int. J. Sustain. Energy* **2003**, *23*, 177–186. [CrossRef]
29. Supapo, K.R.M.; Lozano, L.; Tabañag, I.D.F.; Querikiol, E.M. A Geospatial Approach to Energy Planning in Aid of Just Energy Transition in Small Island Communities in the Philippines. *Appl. Sci.* **2021**, *11*, 11955. [CrossRef]
30. Demiroren, A.; Yilmaz, U. Analysis of change in electric energy cost with using renewable energy sources in Gökçeada, Turkey: An island example. *Renew. Sustain. Energy Rev.* **2010**, *14*, 323–333. [CrossRef]
31. Lambert, T.; Gilman, P.; Lilienthal, P. Micropower system modeling with HOMER. *Integr. Altern. Sources Energy* **2005**, *1*, 379–385.
32. Kaldellis, J.K.; Gkikaki, A.; Kaldelli, E.; Kapsali, M. Investigating the energy autonomy of very small non-interconnected islands: A case study: Agathonisi, Greece. *Energy Sustain. Dev.* **2012**, *16*, 476–485. [CrossRef]
33. Beccali, M.; Ciulla, G.; Di Pietra, B.; Galatioto, A.; Leone, G.; Piacentino, A. Assessing the feasibility of cogeneration retrofit and district heating/cooling networks in small Italian islands. *Energy* **2017**, *141*, 2572–2586. [CrossRef]
34. Calise, F.; Dentice d'Accadia, M.; Macaluso, A.; Vanoli, L.; Piacentino, A. A novel solar-geothermal trigeneration system integrating water desalination: Design, dynamic simulation and economic assessment. *Energy* **2016**, *115*, 1533–1547. [CrossRef]
35. Curto, D.; Favuzza, S.; Franzitta, V.; Guercio, A.; Navia, M.A.N.; Telaretti, E.; Zizzo, G. Grid Stability Improvement Using Synthetic Inertia by Battery Energy Storage Systems in Small Islands. *Energy* **2022**, *254*, 124456. [CrossRef]
36. Andaloro, A.P.F.; Salomone, R.; Andaloro, L.; Briguglio, N.; Sparacia, S. Alternative energy scenarios for small islands: A case study from Salina Island (Aeolian Islands, Southern Italy). *Renew. Energy* **2012**, *47*, 135–146. [CrossRef]
37. Curto, D.; Franzitta, V.; Trapanese, M.; Cirrincione, M. A Preliminary Energy Assessment to Improve the Energy Sustainability in the Small Islands of the Mediterranean Sea. *J. Sustain. Dev. Energy Water Environ. Syst.* **2020**, *8*, 735–753. [CrossRef]
38. Beccali, M.; Bonomolo, M.; Di Pietra, B.; Ippolito, M.G.; La Cascia, D.; Leone, G.; Brano, V.L.; Monteleone, F.; Zizzo, G. Characterization of a small Mediterranean island end-users' electricity consumption: The case of Lampedusa. *Sustain. Cities Soc.* **2017**, *35*, 1–12. [CrossRef]
39. Zizzo, G.; Beccali, M.; Bonomolo, M.; Di Pietra, B.; Ippolito, M.; La Cascia, D.; Leone, G.; Brano, V.L.; Monteleone, F. A feasibility study of some DSM enabling solutions in small islands: The case of Lampedusa. *Energy* **2017**, *140*, 1030–1046. [CrossRef]
40. Ferrari, S.; Zagarella, F.; Caputo, P.; Dall'O', G. A GIS-Based Procedure for Estimating the Energy Demand Profiles of Buildings towards Urban Energy Policies. *Energies* **2021**, *14*, 5445. [CrossRef]
41. Ferrari, S.; Zagarella, F.; Caputo, P.; Dall'O', G. Mapping Buildings' Energy-Related Features at Urban Level toward Energy Planning. *Buildings* **2021**, *11*, 322. [CrossRef]
42. President of Italian Republic. D.P.R. 412, Regolamento Recante Norme per la Progettazione, l'installazione, l'esercizio e la Manutenzione Degli Impianti Termici Degli Edifici ai fini del Contenimento dei Consumi di Energia, in Attuazione Dell'art. 4, Comma 4, Della Legge 9 Gennaio 1991, n. 10. Gazzetta Ufficiale Serie Generale n.242 del 14/10/1993—Supplemento Ordinario n. 96, Rome, Italy. 1993. Available online: https://www.gazzettaufficiale.it (accessed on 14 January 2023).
43. Istat, 15th General Census of Population and Houses. 2011. Available online: https://www.istat.it/it/censimenti-permanenti/censimenti-precedenti/popolazione-e-abitazioni/popolazione-2011 (accessed on 1 March 2022).
44. Municipality of Pantelleria, Agenda per la Transizione Energetica; Isola Di Pantelleria Clean Energy for EU Islands: Brussels, Belgium. 2020. Available online: https://www.comunepantelleria.it/ (accessed on 14 January 2023).

45. Rodonò, G.; Volpes, R. Studio del comportamento termico del dammuso, edificio tipico dell'isola di Pantelleria. In *Volume 1 di Quaderni dell'Istituto di Fisica Tecnica dell'Università di Palermo, 43*; Palermo, Istituto di Fisica Tecnica—Facolta di Ingegneria: Palermo, Italy, 1980.
46. Ferrari, S.; Zanotto, V. Energy Performance Analysis of Typical Buildings. In *Building Energy Performance Assessment in Southern Europe*; A cura di; Springer: Cham, Switzerland, 2016; pp. 79–98.
47. Ferrari, S.; Zagarella, F.; Caputo, P.; Bonomolo, M. Internal heat loads profiles for buildings' energy modelling: Comparison of different standards. *Sustain. Cities Soc.* **2023**, *89*, 104306. [CrossRef]
48. *ISO 52000*; Energy Performance of Buildings—Overarching EPB Assessment—Part 1: General Framework and Procedures. ISO: Geneva, Switzerland, 2017.
49. *ISO 17772-1*; Energy Performance of Buildings—Indoor Environmental Quality—Part 1: Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings. ISO: Geneva, Switzerland, 2017.
50. *ISO/TR 17772-2*; Energy Performance of Buildings—Overall Energy Performance Assessment Procedures—Part 2: Guideline for Using Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings. ISO: Geneve, Switzerland, 2018.
51. *ISO 15193*; Energy Performance of Buildings—Energy Requirements for Lighting. ISO: Geneva, Switzerland, 2017.
52. Ferrari, S.; Zanotto, V. Thermal Comfort Approaches and Building Performance. In *Building Energy Performance Assessment in Southern Europe*; Springer Briefs in Applied Sciences and Technology; Springer: Cham, Switzerland, 2016; pp. 47–60.
53. Klein, S.A.; Beckman, W.A.; Mitchell, J.W.; Duffie, J.A.; Duffie, N.A.; Freeman, T.L.; Mitchell, J.C.; Braun, J.E.; Evans, B.L.; Kummer, J.P.; et al. *TRNSYS—A Transient System Simulation Program User Manual*; The Solar Energy Laboratory—University of Wisconsin: Madison, WI, USA, 2014.
54. Comitato Termotecnico Italiano. *Prestazioni Energetiche Degli Edifici: Climatizzazione Invernale e Preparazione Acqua Calda per Usi Igienico-Sanitari Volume CTI–R 03/3*; Comitato Termotecnico Italiano: Milano, Italy, 2003.
55. Beccali, M.; Bonomolo, M.; Ciulla, G.; Colombarini, R.; Leone, G.; Martorana, F.; Mineo, L.; Musca, R.; Piacentino, A.; Telaretti, E.; et al. *LA4.4 Studio di Fattibilità di Soluzioni per L'efficientamento Energetico Delle Isole Minori*; ENEA—Ricerca di Sistema Elettrico: Roma, Italy, 2021.
56. QGIS. *org. QGIS Geographic Information System*; QGIS Association: Beaverton, OR, USA, 2022; Available online: https://www.qgis.org/it/site/ (accessed on 14 January 2023).
57. Municipality of Pantelleria, Geoportal+ Comune di Pantelleria. 2022. Available online: https://geoportalplus.nemea.cloud/pantelleria.php (accessed on 1 March 2022).
58. Municipality of Pantelleria, Detailed Masterplan of Pantelleria Main Town. 2008. Available online: https://www.comunepantelleria.it/organizzazione-uffici/territorio-e-riqualificazione-urbana/piano-particolareggiato/ (accessed on 1 March 2022).
59. Google Earth. 2022. Available online: earth.google.com/web/ (accessed on 1 March 2022).
60. Municipality of Pantelleria. *Piano d'Azione per l'Energia Sostenibile*; Municipality of Pantelleria: Pantelleria, Italy, 2015.
61. MiSE. *Decreto Ministeriale 26/06/2015. Applicazione delle Metodologie di Calcolo delle Prestazioni Energetiche e Definizione delle Prescrizioni e dei Requisiti Minimi degli Edifici*; Gazzetta Ufficiale: Rome, Italy, 2015.